Support Dynamically Linked Executables via Linux ld.so and Implement ENA Driver

Expand Application of OSv

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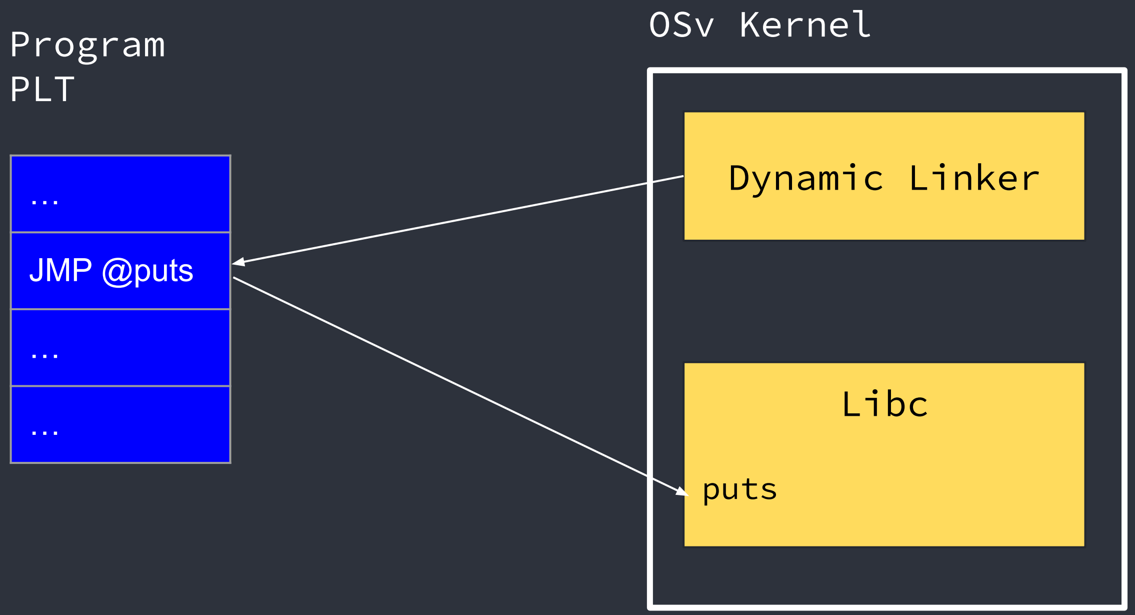
Agenda

- Support statically linked executables and dynamically linked executables via Linux ld.so
- ENA driver and AWS Nitro
- XConfig preview
- Upcoming 1.0 release and beyond

OSv built-in dynamic linker and libc

- Most applications do NOT make system calls into Linux kernel directly
- Instead, they call libc functions that delegate to SYSCALL or SVC instruction
- The OSv built-into-kernel dynamic linker memory-maps ELF files and resolves the undefined symbols by pointing them to OSv implementations
- Supported types
  - Shared Libraries and Dynamically Linked Executables
  - PIEs and non-PIC
- Benefit
  - Fast local function calls without SYSCALL/SVC overhead
- Drawback
  - Linux compatibility is a moving target

OSv built-in dynamic linker and libc



Program
PLT

...

JMP @puts

...

...

OSv Kernel

Dynamic Linker

Libc

puts

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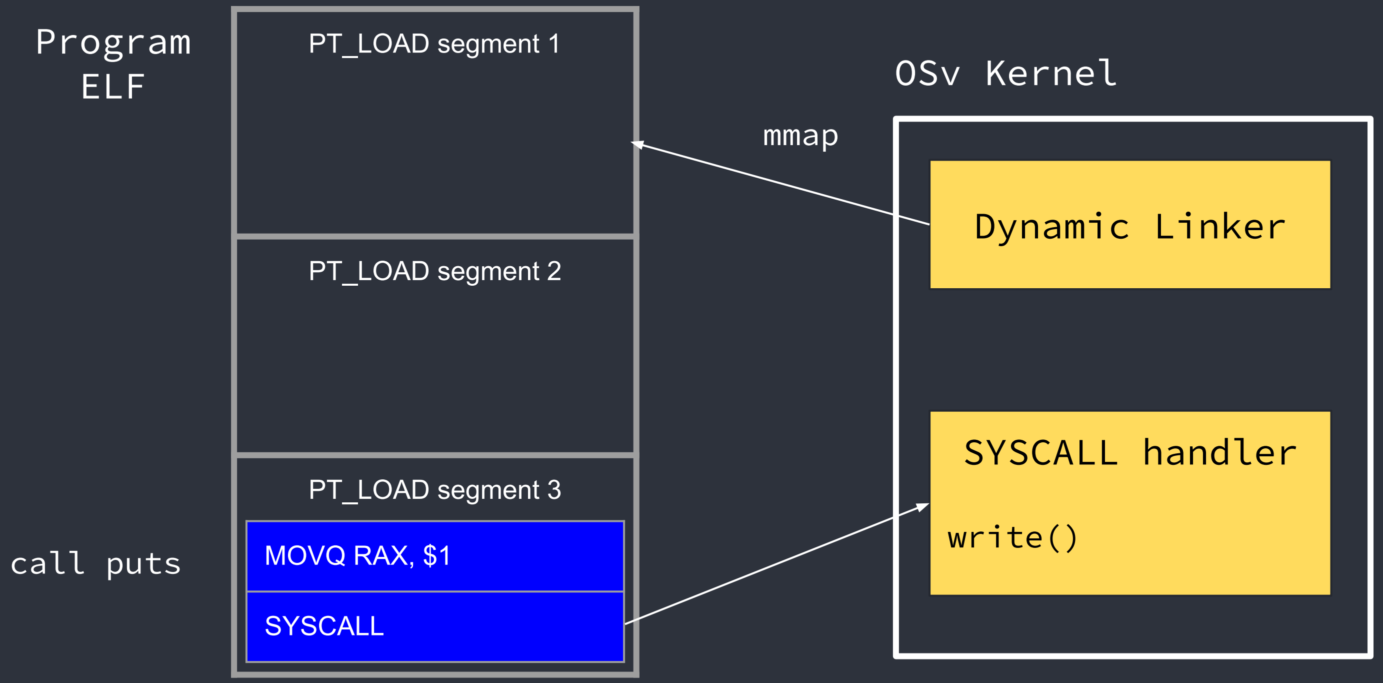
Statically linked executable

- Statically linked executables make direct system calls to Linux kernel
- OSv initially implemented ~70 syscalls to support Golang executables
- ~60 new syscalls implemented including the key ones like brk() and clone() in order to support statically linked executables
- Most challenging part was to support application thread-local storage (TLS)
- Expose vDSO as part of the kernel image
- Benefit
  - Better Linux compatibility
- Drawback
  - Overhead of system calls

Statically linked executable



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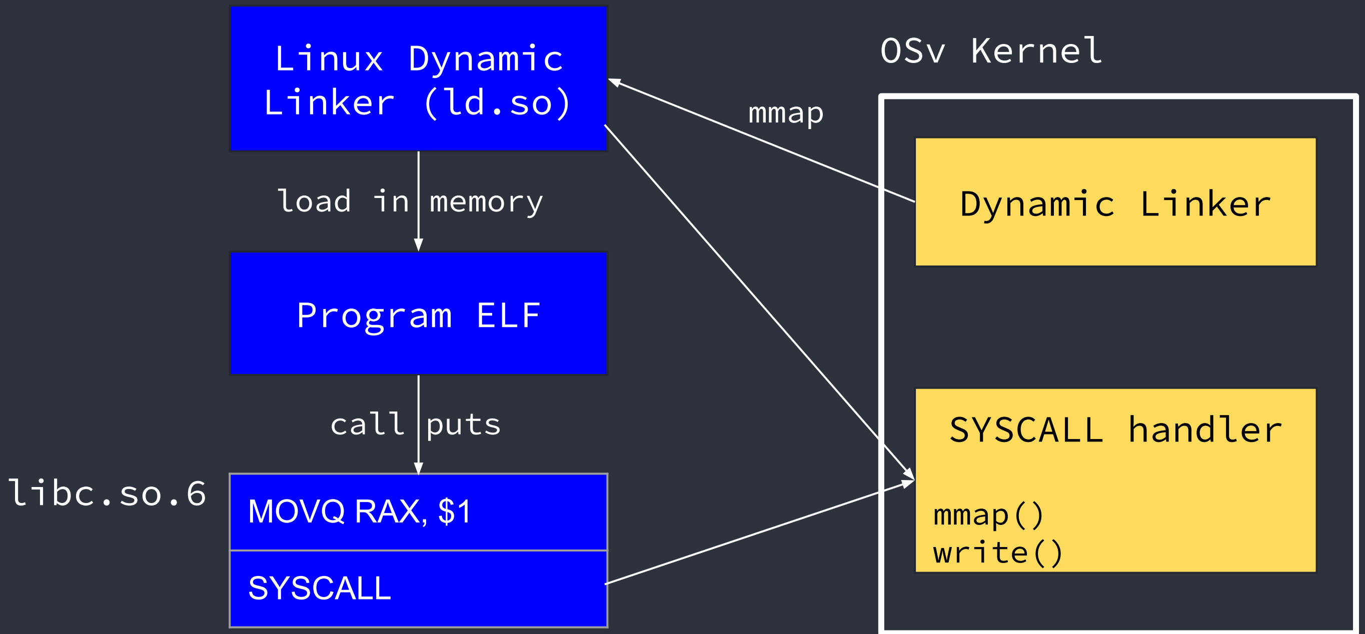
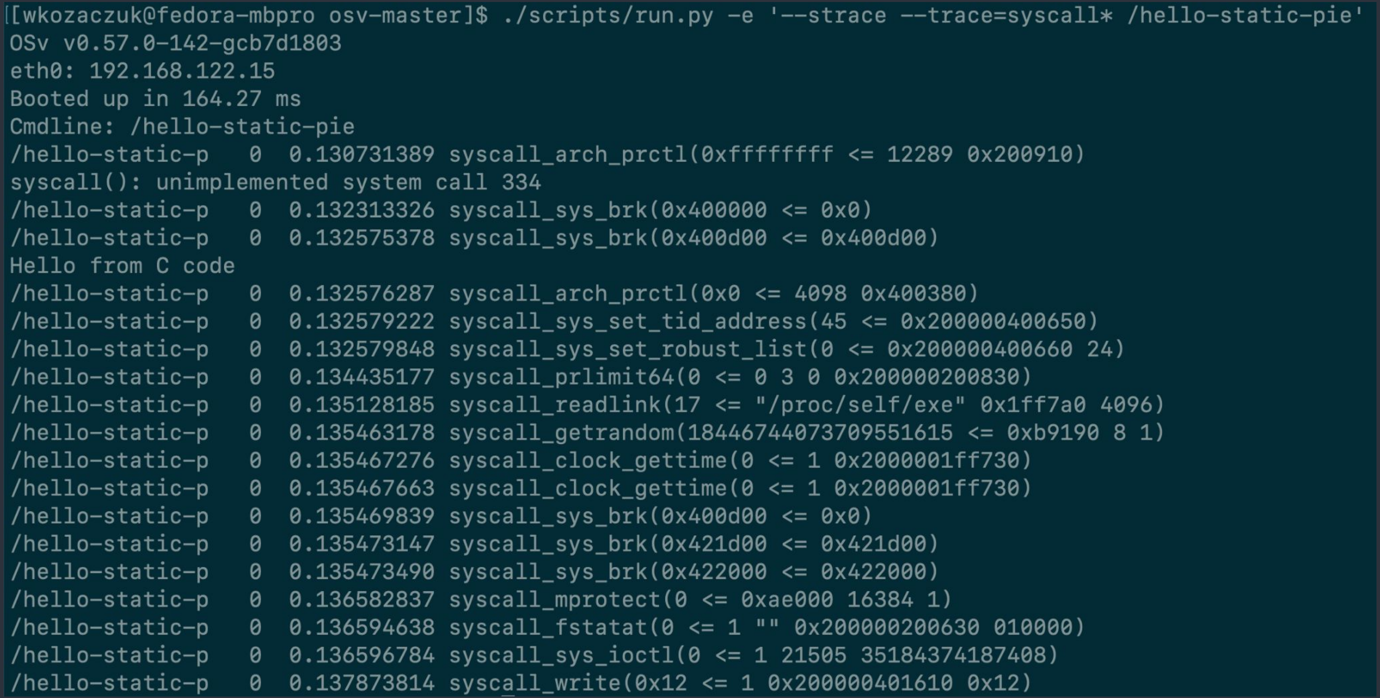
Linux dynamic linker and glibc

- Run dynamically linked programs using the Linux dynamic linker (LD) instead of the OSv built-in one
    - **scripts/run.py -e '/lib64/ld-linux-x86-64.so.2 /hello'**
- Needs to add **ld-linux-x86-64.so.2** or **ld-linux-aarch64.so.1** and other libc library files to the image
- Benefits
    - Better Linux compatibility
    - Ability to take advantage of glibc optimizations
- Drawbacks
    - Overhead of system calls
    - Inability to use the OSv libc optimizations

Linux dynamic linker and glibc



Strace



```
[wkozaczuk@fedora-mbpro osv-master]$ ./scripts/run.py -e '--strace --trace=syscall* /hello-static-pie'
OSv v0.57.0-142-gcb7d1803
eth0: 192.168.122.15
Booted up in 164.27 ms
Cmdline: /hello-static-pie
/hello-static-p   0  0.130731389 syscall_arch_prctl(0xffffffff <= 12289 0x200910)
syscall(): unimplemented system call 334
/hello-static-p   0  0.132313326 syscall_sys_brk(0x400000 <= 0x0)
/hello-static-p   0  0.132575378 syscall_sys_brk(0x400d00 <= 0x400d00)
Hello from C code
/hello-static-p   0  0.132576287 syscall_arch_prctl(0x0 <= 4098 0x400380)
/hello-static-p   0  0.132579222 syscall_sys_set_tid_address(45 <= 0x200000400650)
/hello-static-p   0  0.132579848 syscall_sys_set_robust_list(0 <= 0x200000400660 24)
/hello-static-p   0  0.134435177 syscall_prlimit64(0 <= 0 3 0 0x200000200830)
/hello-static-p   0  0.135128185 syscall_readlink(17 <= "/proc/self/exe" 0x1ff7a0 4096)
/hello-static-p   0  0.135463178 syscall_getrandom(18446744073709551615 <= 0xb9190 8 1)
/hello-static-p   0  0.135467276 syscall_clock_gettime(0 <= 1 0x2000001ff730)
/hello-static-p   0  0.135467663 syscall_clock_gettime(0 <= 1 0x2000001ff730)
/hello-static-p   0  0.135469839 syscall_sys_brk(0x400d00 <= 0x0)
/hello-static-p   0  0.135473147 syscall_sys_brk(0x421d00 <= 0x421d00)
/hello-static-p   0  0.135473490 syscall_sys_brk(0x422000 <= 0x422000)
/hello-static-p   0  0.136582837 syscall_mprotect(0 <= 0xae000 16384 1)
/hello-static-p   0  0.136594638 syscall_fstatat(0 <= 1 "" 0x200000200630 010000)
/hello-static-p   0  0.136596784 syscall_sys_ioctl(0 <= 1 21505 35184374187408)
/hello-static-p   0  0.137873814 syscall_write(0x12 <= 1 0x200000401610 0x12)
```

ENA Driver

Implement the AWS ena driver by porting the FreeBSD version

- Adapt the FreeBSD code to make it work in OSv
- Minimize changes so that we can backport any potential bug fixes or enhancements in the future
- Reduce the code footprint by eliminating features that are either not relevant to OSv or not needed at this point (like ioctl(), sysctl(), etc)

- Resulting driver "costs" ~7k lines of mostly C code and ~56K larger kernel size
- Can only be tested on AWS Nitro EC2 instance
- Seems to be stable and yield decent performance based on the tests involving iperf3, netperf, and simple httpserver app

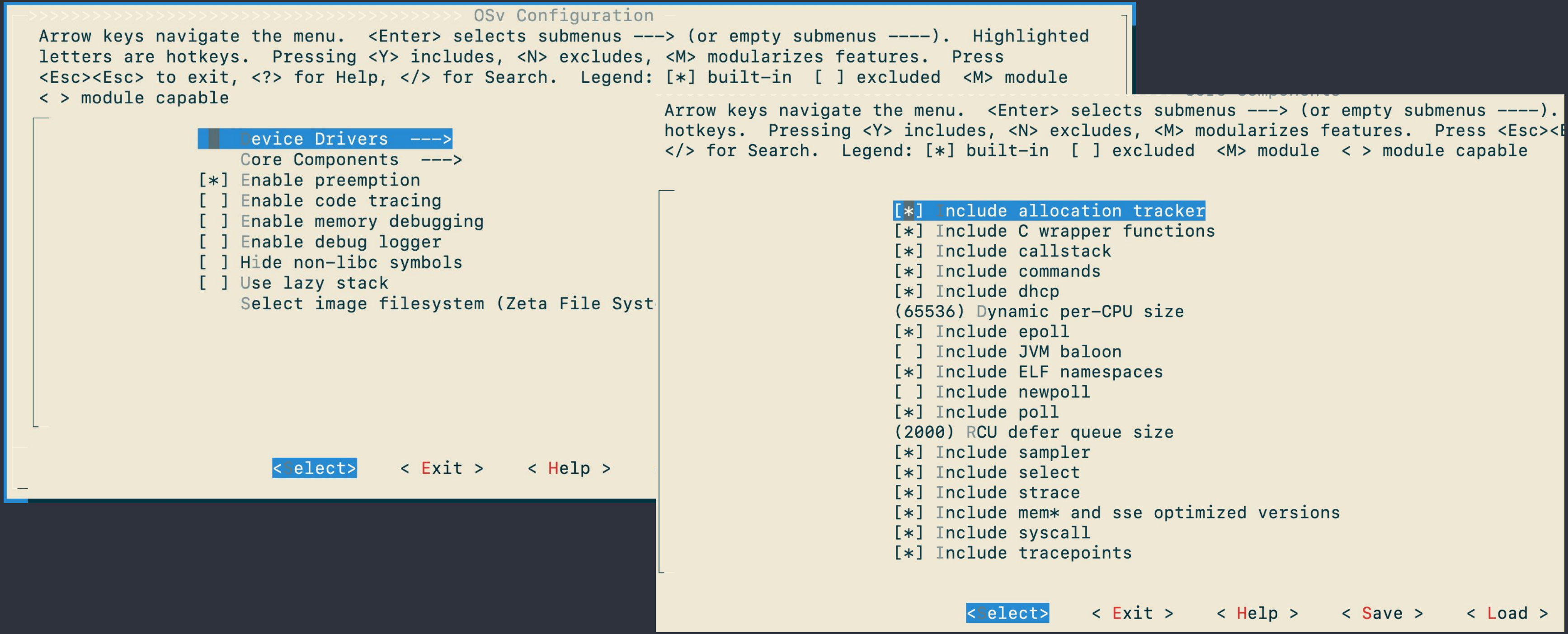
AWS Nitro

- ENA driver is enough to run OSv image with ramfs on Nitro EC2 instances
- New script **deploy_to_aws.sh** to streamline the process of uploading OSv image as a snapshot, creating AMI and finally instantiating EC2 instance
- NVMe driver is WIP

XConfig - WIP

- Continuation of the modularization / driver profiles effort
- Xconfig files
- Add #ifdef in relevant places
- Makefile acts on .config
  - Include/exclude relevant object files
  - Pass configuration options to relevant source files
- Let garbage collection remove remaining stuff

XConfig - menu example



```
 OSv Configuration
 Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus ----).  Highlighted
 letters are hotkeys.  Pressing <Y> includes, <N> excludes, <M> modularizes features.  Press
 <Esc><Esc> to exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ] excluded  <M> module
 < > module capable

                   Device Drivers  --->
                   Core Components  --->
               [*] Enable preemption
               [ ] Enable code tracing
               [ ] Enable memory debugging
               [ ] Enable debug logger
               [ ] Hide non-libc symbols
               [ ] Use lazy stack
                   Select image filesystem (Zeta File Syst

                  <Select>    < Exit >    < Help >
```

```
 Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus ----).
 hotkeys.  Pressing <Y> includes, <N> excludes, <M> modularizes features.  Press <Esc><E
 </> for Search.  Legend: [*] built-in  [ ] excluded  <M> module  < > module capable

                      [*] Include allocation tracker
                      [*] Include C wrapper functions
                      [*] Include callstack
                      [*] Include commands
                      [*] Include dhcp
                      (65536) Dynamic per-CPU size
                      [*] Include epoll
                      [ ] Include JVM baloon
                      [*] Include ELF namespaces
                      [ ] Include newpoll
                      [*] Include poll
                      (2000) RCU defer queue size
                      [*] Include sampler
                      [*] Include select
                      [*] Include strace
                      [*] Include mem* and sse optimized versions
                      [*] Include syscall
                      [*] Include tracepoints

                   <Select>    < Exit >    < Help >    < Save >    < Load >
```

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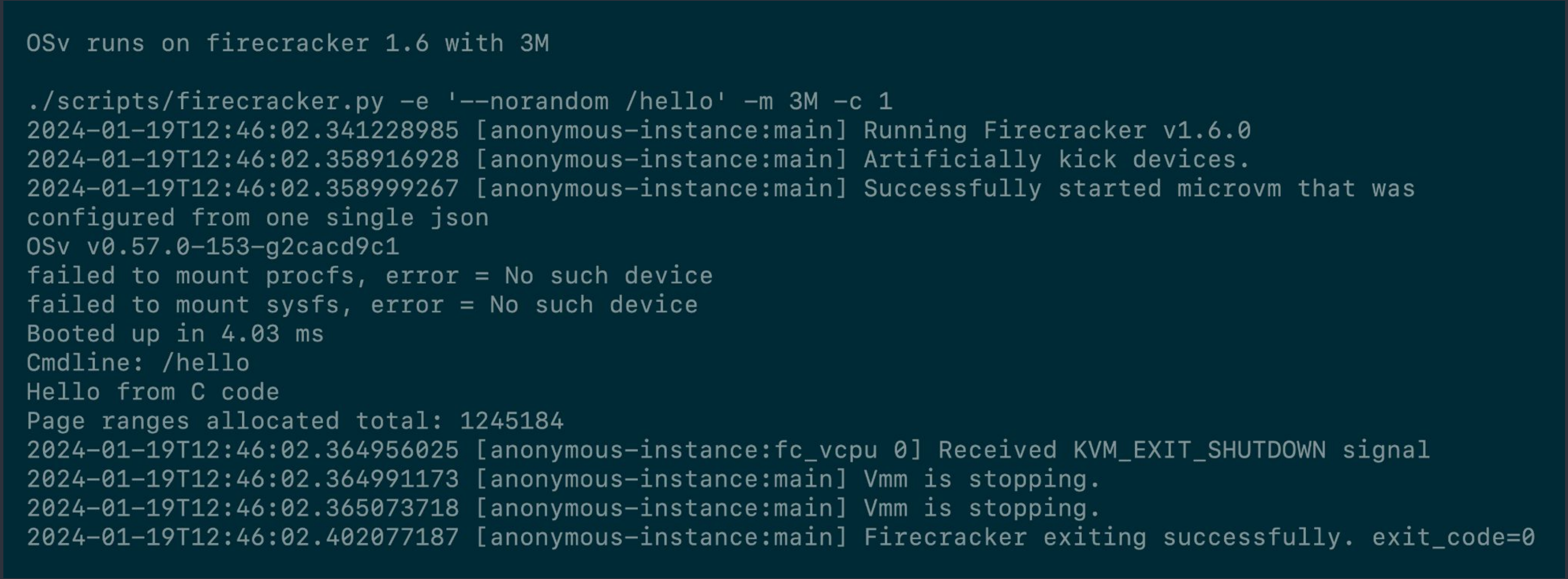
788K loader.elf uses 1.2M of memory

- Optimize kernel size to 788L to run on Firecracker with < 2MB of memory
- Reduce kernel size by:
  - Hiding most symbols
  - Excluding all drivers but virtio/mmio
  - Excluding tracepoints, dhcp and networking stack code
  - Excluding std::locale
  - Eventually enable LTO (Link Time Optimization)
- Lower memory usage by:
  - Reducing RCU defer queue
  - Reducing L1/L2 memory pool size
  - Disabling procfs and sysfs
  - Reducing kernel thread stack size to 16K

788K loader.elf uses 1.2M of memory



```
OSv runs on firecracker 1.6 with 3M

./scripts/firecracker.py -e '--norandom /hello' -m 3M -c 1
2024-01-19T12:46:02.341228985 [anonymous-instance:main] Running Firecracker v1.6.0
2024-01-19T12:46:02.358916928 [anonymous-instance:main] Artificially kick devices.
2024-01-19T12:46:02.358999267 [anonymous-instance:main] Successfully started microvm that was
configured from one single json
OSv v0.57.0-153-g2cacd9c1
failed to mount procfs, error = No such device
failed to mount sysfs, error = No such device
Booted up in 4.03 ms
Cmdline: /hello
Hello from C code
Page ranges allocated total: 1245184
2024-01-19T12:46:02.364956025 [anonymous-instance:fc_vcpu 0] Received KVM_EXIT_SHUTDOWN signal
2024-01-19T12:46:02.364991173 [anonymous-instance:main] Vmm is stopping.
2024-01-19T12:46:02.365073718 [anonymous-instance:main] Vmm is stopping.
2024-01-19T12:46:02.402077187 [anonymous-instance:main] Firecracker exiting successfully. exit_code=0
```

Upcoming 1.0 release

- Planned for 1st quarter of 2024
- Remaining work:
    - Finish KConfig work
    - Add support of Ext2/3/4 filesystem
    - Merge IPV6 branch
    - Potentially implement NVMe driver
        - There are 2 PRs as candidates

Beyond 1.0

- Capstan 2
    - Remove obsolete features and add new desired functionality
    - Support building images out of binaries or packages, running those locally, and provisioning to the cloud
- Peformance and Security
    - Optimize futex
    - Add some spinning to lock-less mutex_lock
    - Optimize atomic operations on single CPU
    - Implement ALSR and make kernel relocatable
- Support AWS Graviton
    - Implement UEFI boot
    - Implement MSI/X and ACPICA on AArch64

Thanks

- Organizers
- ScyllaDB
  - Dor Laor
  - Nadav Har’El
- Other OSv contributors
- Please join us

OSv Resources and Q&A

- Original OSv paper - https://www.usenix.org/system/files/conference/atc14/atc14-paper-kivity.pdf
- P99 presentation - https://www.p99conf.io/session/osv-unikernel-optimizing-guest-os-to-run-stateless-and-serverless-apps-in-the-cloud/
- FOSDEM 23 - https://archive.fosdem.org/2023/schedule/event/osvevolution/
- Wiki pages:
  - Components of OSv - https://github.com/cloudius-systems/osv/wiki/Components-of-OSv
  - Memory Management - https://github.com/cloudius-systems/osv/wiki/Memory-Management
  - Networking Stack - https://github.com/cloudius-systems/osv/wiki/Networking-Stack
  - Modularization - https://github.com/cloudius-systems/osv/wiki/Modularization
  - Filesystems - https://github.com/cloudius-systems/osv/wiki/Filesystems